Beamline 9.0.1

Coherent Optics Experiments

Microscopic return point memory in perpendicular ferromagnetic Co/Pt multilayer films

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In his 1905 dissertation, Madelung described the phenomenon of return point memory in magnetic hysteresis loops. Despite a century of subsequent work on magnetism, the subject remains largely unstudied and has only recently been the focus of renewed theoretical interest. Madelung's rules describing the return point memory are illustrated in Fig. 1: (1) Any minor curve Γ_1 that starts at point P on the major magnetization loop is uniquely determined by the coordinates of P. (2) If any point Q on the minor curve becomes a second turning point, then the new curve Γ_2 returns to its original point P on the major loop. (3) If the curve Γ_2 continues beyond point P, then it coincides with the continuation of the original major loop past P. Madelung's macroscopic characterization raises the interesting question of what happens at the microscopic level: under the same minor loop cycle, do the ferromagnetic domains exhibit the same microscopic configuration when returning to the major loop? The high degeneracy of hysteretic systems implies that many microscopic configurations lead to the same macroscopic magnetization, and one might therefore not expect to observe microscopic return point memory (μRPM) in connection with macroscopic return point memory.

We have applied coherent soft-x-ray magnetic scattering to test the extent of μRPM in Co/Pt multilayer films. We find that μRPM is indeed observed, but only for limited field excursions. For applied fields that take the system near magnetic saturation, μRPM is increasingly destroyed. More precisely, this phenomenon is related to a change in the microscopic morphology of the magnetic domains that occurs near saturation. Near remanence, the domains exhibit short-range positional order, and the magnetostatic energy associated with this order to acts to prevent structural relaxation. Near saturation, the short-range order is quenched in favor or random, spatially uncorrelated domains. This microstructure does not support μRPM.

Scattering experiments were performed using quasi-direct, spatially-filtered undulator light on beamline 9.0.1 at the ALS. The transversely coherent x-ray beam at λ = 1.6 nm (the cobalt L-edge) is scattered on transmission at normal incidence through a Co/Pt multilayer film, and the diffuse light is collected by a soft x-ray CCD camera downstream. Our sample was grown by magnetron sputtering onto a smooth, low-stress, 160-nm-thick SiN_x membrane at 250^o C. The sample consists of a 20-nm-thick Pt buffer layer, 50 repeating units of a 4-Å cobalt and 7-Å Pt layers, and a 3-nm-thick Pt cap which prevents oxidation. An electromagnet was used to apply magnetic fields perpendicular to film.

A typical scattering pattern from the Co/Pt film at an applied field of 0.25 kOe is shown in Fig. 2. Near remanence, the dominant structure is a ring of diffusely scattered light. Such a scattering pattern is reminiscent of a classical liquid exhibiting short-range positional correlation. This ring gradually disappears as saturation is approached, indicating the loss of short-range order near saturation. The intensity of the ring is plotted in Fig. 3, and it is apparent that short-range order is completely extinguished by a field H = 2.5 kOe. Closer examination indicates that the scattering pattern in Fig. 2 is speckled, exhibiting reproducible graininess with well-defined statistical properties that arises from our use of a transversely coherent beam. We can determine the extent of μRPM by cross-correlating such speckle patterns since even small changes in the magnetic domains will produce observable changes in the speckle pattern.

Our most important results are given by the open circles in Fig.3. These measure the degree of μRPM for a complete minor loop as in the inset of Fig. 1, as a function of the field H* at the point on the major loop P = P' where the minor loop begins and ends. The correlation coefficient <p> remains close to unity H* < 1.5 kOe, indicating essentially perfect return point memory. At larger H*, <p> deviates increasingly from unity, implying that μRPM is correspondingly less valid. An important conclusion to be drawn from these results is that the extent of μRPM is directly related to domain microstructure. The destruction of short-range domain correlations is complete at a field of ~2.5 kOe, or very close to where μRPM is completely destroyed. A more general statement, therefore, is that observation of MRPM depends on the degree to which the domains maintain short range correlations. As a function of H*, the liquid intensity falls significantly more quickly than the <p>, implying a rather strong and nonlinear scaling relationship between these two. This scaling relationship qualitatively resembles percolation: a percolating random system approaches macroscopic connectivity with power law behavior as a function of average particle density. Percolation is thought to play a key role in the colossal magnetoresistence (CMR) effect observed in manganite compounds implying that there may be a fundamental linkage between CMR and microscopic return point memory.

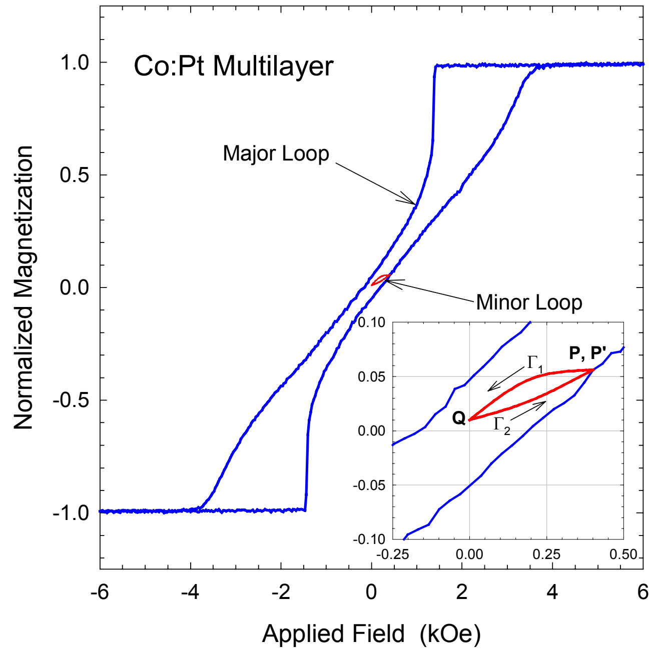

Fig. 1. Measured major magnetization loop for the Co/Pt multilayer film with the magnetic field applied perpendicular to the film. The inset exemplifies the kind of minor loop studied which departs the major loop at P, extends on the branch labeled Γ_1 to zero applied field at Q, and then returns on the branch labeled Γ_2 to the major loop at P' = P.

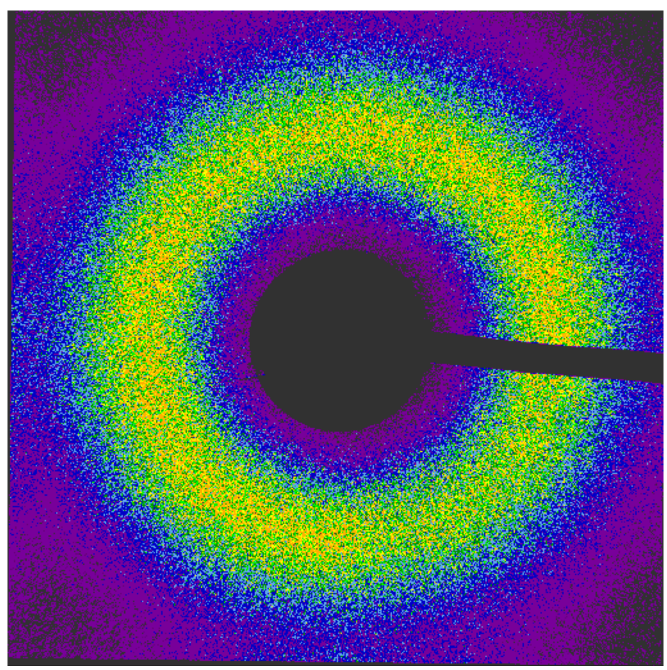

Fig. 2. CCD image of speckle-diffraction patterns collected in transmission through the Co/Pt multilayer film at an applied field H* = 0.25 kOe. Magnetic contrast is provided by operating at a soft x-ray wavelength near the Co L-edge. The dark region in the middle of the image is a blocker inserted to eliminate the direct beam.

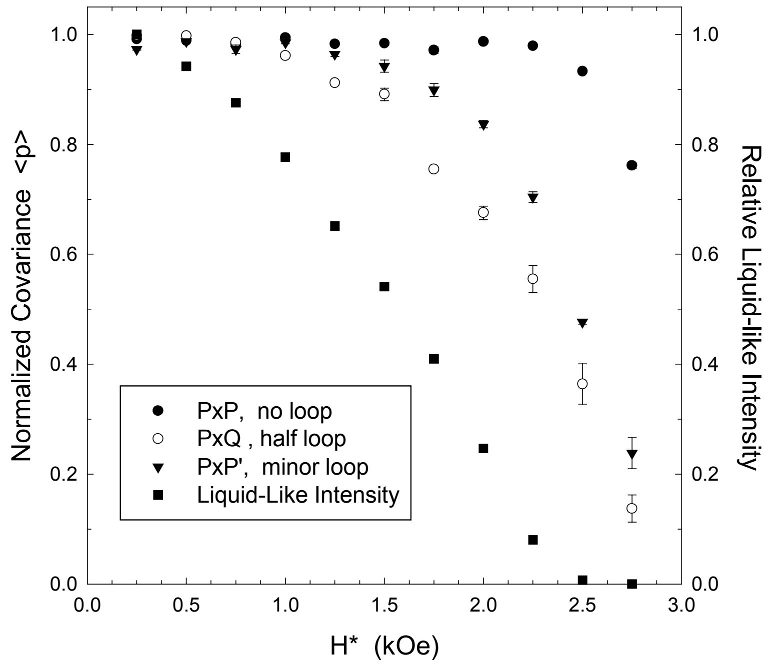

Fig. 3. Summary of μRPM results obtained by comparing pairs of speckle pattern collected at the turning points of a minor loop. The normalized covariance is unity for images with identical speckle patterns and zero for images with completely different speckle patterns. The field H* corresponds to the field at P in the minor loop in the inset of Fig. 1. At low and moderate H*, the system exhibits good microscopic return point memory. The bottom data set plots the degree of short-range correlation in the magnetic domains, as measured by the area of the peak in the scattering profiles in Fig. 2. There is seen to a strong correlation between short-range order and microscopic return point memory.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of our research by the U.S. Department of Energy, Division of Materials Science, under grants DE-FG03-99ER45776, DE-FG06-86ER45275, and DE-AC03-76SF00098, and for their support of the Advanced Light Source under grant DE-AC03-76SF00098.

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